INTERSTATE COMMERCE COMMISSION.

REPORT OF THE CHIEF OF THE DIVISION OF SAFETY, COVERING THE INVESTIGATION OF AN ACCIDENT WHICH OCCURRED ON THE BALTIMORE & OHIO RAILROAD NEAR WOODLYN, PA., ON SEPTEMBER 19, 1914.

December 23, 1914.

To the Commission:

On September 19, 1914, there was a derailment of a passenger train on the Baltimore & Ohio Railroad near Woodlyn, Pa., which resulted in the injury of 34 passengers, 3 Pullman employees, and 1 employee of the railroad. After investigation of this accident the Chief of the Division of Safety reports as follows:

Westbound passenger train No. 3 consisted of 2 mail cars, 1 combination baggage and express car, 1 smoking car, 1 coach, 2 Pullman sleeping cars, and 1 parlor car. The coach and the parlor car had steel underframes, the other cars being of all-steel construction. This train was hauled by locomotive No. 5103, and was in charge of Conductor Anderson and Engineman Way. It left Philadelphia at 9.25 p. m., four minutes late, and at 9.40 p. m. was derailed at a point about 1,600 feet west of the station at Woodlyn, Pa., which is 10.4 miles from Philadelphia, on account of the breaking of the forward axle of the locomotive tender. The speed at the time of derailment was 57 miles per hour.

After derailment the tender wheels ran along on the ties until they reached the western end of the north passing track. At this point the frog was torn out and the entire train derailed. About 150 feet beyond this point is a double-track, single-span, trussed bridge 167 feet 4 inches in length. The locomotive and first five cars passed over the bridge in safety, the locomotive coming to a stop 710 feet beyond the western end of the bridge with the derailed tender coupled to it. About 25 feet north of the locomotive were the first four cars of the train, upright on the ties. The fifth car turned over to the right immediately after crossing the bridge and came to rest with its roof against a telegraph pole, at the top of a 25-foot embankment. The sixth car, the all-steel Pullman sleeping car Rachita, swerved to

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No 1.—General view of the derailment looking south.

No. 2.—View of wrecked bridge looking north, showing steel car on its side at foot of embankment.

the right enough to strike the end post of the right-hand truss of the bridge, after which it plunged to the track below, a distance of about 25 feet. The second Pullman sleeping car stopped with its forward end projecting over the bridge abutment and was also leaning to the right against a telegraph pole. The last car in the train, a parlor car, was also derailed, but remained upright at the top of the embankment, immediately behind the second sleeping car. The damage caused to the bridge by the sleeping car Rachita caused its collapse. Illustration No. 1 is a general view of the accident, looking in the direction in which the train was moving. Illustration No. 2 is a view looking in the opposite direction and shows in particular the condition of the bridge after the accident.

This division of the Baltimore & Ohio Railroad is a double-track line, train movements being protected by the automatic block signal system. The track is straight, with a descending grade for westbound trains of 0.8 per cent. It is laid with 100-pound rails 33 feet in length, with about 18 pine and oak ties under each rail. The ballast consists of 12 inches of crushed stone, and the general condition of the track was excellent. The weather was clear.

Examination of the track showed that the first mark of derailment was about 400 feet east of the station, at which point a tie, slightly higher than the rest, had a small groove cut in it. One hundred and twelve feet beyond there was another tie with a deeper groove in it. At the eastern end of the station platform a plank on the right side of the track was torn up, while at a highway crossing 150 feet beyond were the first indications that the tender wheels had left the rails, a crossing plank on the outside of the right-hand rail having been torn up, while a plank on the inside of the opposite rail was split and showed marks of a wheel flange having caused it. From this point to the switch at the western end of the north passing track, a distance of 735 feet, the tender wheels ran along on the ties. After tearing out the frog at this switch the entire train was derailed with the exception of the engine.

The trucks under the tender of locomotive No. 5103 were of 100 tons capacity, built by the Baldwin Locomotive Works in July, 1913, and placed in service the following month. The axles were of forged steel, with a 6 by 11 journal bearing, and a wheel fit measuring $7\frac{5}{8}$ by $8\frac{1}{4}$. It was within this wheel fit that the break occurred, nearly square across the axle, varying from three-sixteenths to seven-sixteenths inch in from the outside face of the hub of the wheel. The break was a detailed or progressive type of fracture, which extended in from one side of the axle, leaving only about 26 per cent of the metal intact. It was the breaking of this last portion which was the immediate precursor of this accident.

The investigation to determine the reason for the failure of this axle was conducted by Mr. James E. Howard, engineer physicist, whose report immediately follows.

The fractured axle represents one of the largest in common use for tender trucks. It was furnished under the specifications of the Baltimore & Ohio Railroad Co., which call for the dimensions given on the following sketch.

The specifications state that axles shall be made of steel, the desired composition of which is—

	Per cent.
Carbon	0.45
Manganese, not above	.50
Silicon	.05
Phosphorus, not above	.04
Sulphur, not above	.04

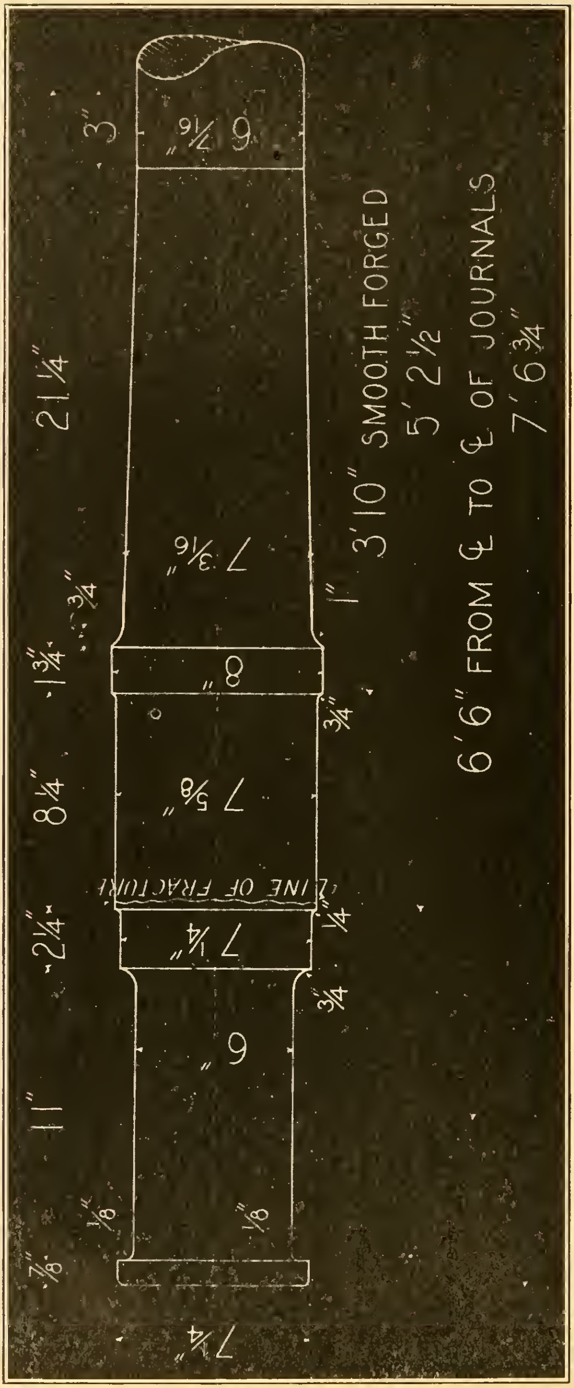
Axles will be considered as having failed chemically and will be rejected if the analysis shows the constituents to be outside the following limits:

		Per cent.
Carbon	below 0.35 or above	0.55
Manganese	above	.50
Phosphorus	above	.06
Sulphur	above	.05

Axles of this size are required to stand a drop test of 7 blows of a 1,640-pound tup, dropped from a height of 52 feet, the deflection under the first blow not to exceed 4¼ inches. During the test they are to rest upon supports 3 feet apart, the tup striking the axle midway its length. The axle to be turned (that is, rotated 180°) after the first and third blows and when required after the fifth.

This axle bore the brand mark "Pollak," of the Pollak Steel Co., at the middle of its length. It was finished and assembled by the Baldwin Locomotive Works. The ends of the journals were stamped "7 13 100 B L W," and "7 13 80 B L W," on the fractured and intact ends, respectively. These marks indicate that the wheels were pressed on the axle at the Baldwin Locomotive Works in the month of July, 1913, and that a pressure of 100 tons was used for the wheel at the fractured end and 80 tons for the opposite wheel.

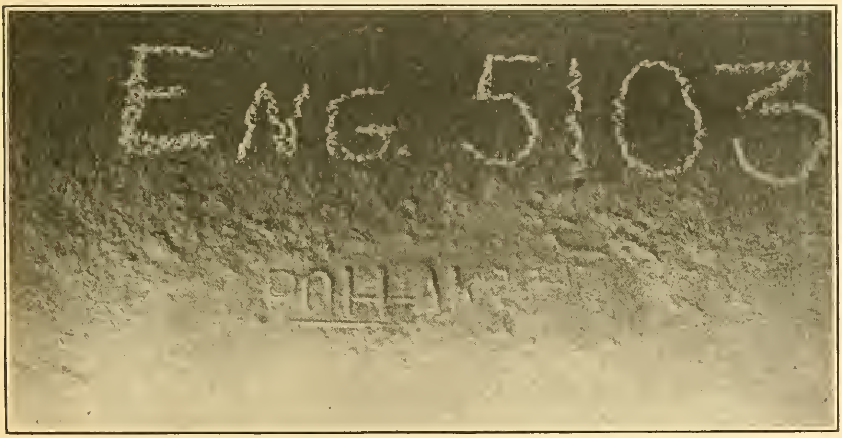
Rolled steel wheels were used, made by the Standard Steel Works Co. The wheel on the fractured end of the axle was branded "S S S 6 28 13 673 15542," that on the other end, "6 29 13 428." The total weight of the tender under which this axle was used was 165,000 pounds, an average load of 20,625 pounds per wheel. The bearing surfaces of the journals were in good condition, showing no wear of consequence, the wheels also being in good order. The wheel at the intact end shows a little more flange wear than its mate, but each were in a satisfactory condition.



No. 3.—Sketch showing dimensions of fractured tender axle, with line of fracture indicated thereon.

An examination was made of the fractured axle for concentricity in running, with wheels still in place. For this purpose it was centered in a lathe and there rotated. It was found to be substantially in normal condition, notwithstanding the vicissitudes through which it had passed at the time of derailment. No contributory cause leading to its failure was revealed at this time.

The wheels were next pressed off the axle. The one at the fractured end required a force of 375 tons to remove it; that on the intact end 145 tons pressure. The surfaces of the axle at the wheel fits were now exposed to view. That on the intact end was in good condition and presented a normal appearance. The surface at the fractured end, however, was characterized by the presence of a considerable number of marks or serrations made by some blunt-edged tool, which, as a group, covered about two-thirds of the circumference. They were located on the side of the axle which first rup-



No. 4.—Brand mark "Pollak" on axle at middle of length.

tured and symmetrical with that side. The significance of these serrations in respect to their indicating a cause for the failure of the axle and their probable origin will be referred to in a later part of this report.

The dismantled axle was subjected to a drop test. It endured the seven prescribed blows without fracture. The deflection caused by the first blow was 1.8 inches. An eighth blow was struck to straighten the axle. Two longitudinal seams were developed along the length of the axle, one near the middle and one near the intact end. No particular significance is attached to the development of these seams in respect to influencing the failure of the axle at the time of derailment. They represented the development of seams which were in the forging but of a kind which service conditions would not be expected to develop.

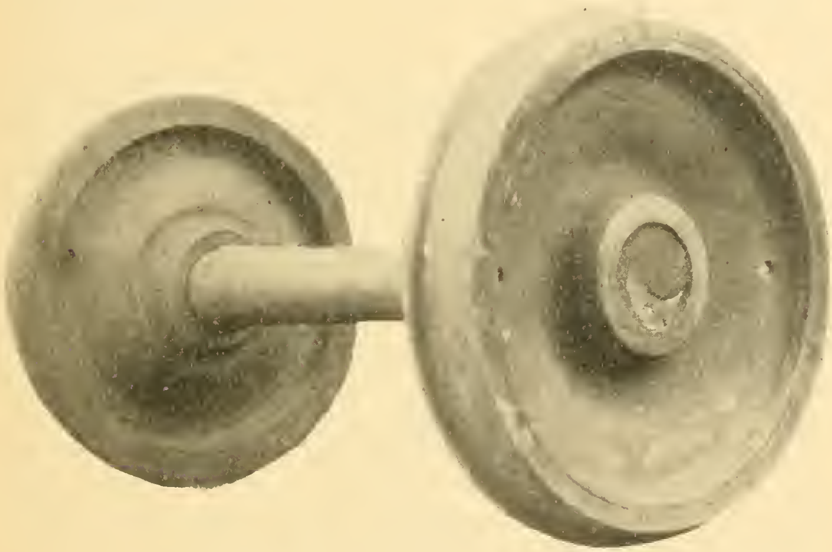
The axle was next cut up for metallographic examination, chemical analysis, and physical tests. This work was done in the shops and laboratory of the Baltimore & Ohio Railroad Co., which company cooperated with the Division of Safety in the acquisition of these data in a very efficient and satisfactory manner. Chips for chemical analysis were taken from different parts of the cross section, near the finished surface or circumference of the axle, one quarter below the surface diametrically, and at the center of the section. Two sets of chips were taken, one representing the metal in the vicinity of the place of rupture, the other the opposite end of the axle.

No. 5.—Marks stamped on end of fractured journal 7 13 100 B L W, indicating date wheel was pressed on axle and pressure, in tons, used.

The results of the chemical analyses were as follows:

Location.	Carbon.	Sulphur.	Phosphorus.	Manganese.
Fractured end of axle:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Near circumference	0.39	0.039	0.026	0.45
One-quarter below surface	.37	.038	.023	.47
Center of section	.38	.039	.025	.46
Intact end of axle:				
Near circumference	.40	.037	.025	.44
One-quarter below surface	.37	.040	.025	.45
Center of section	.39	.039	.024	.46

Hardness tests by means of the scleroscope were made on the surface of the wheel fit, near the place of fracture, and on two cross sections in the same vicinity. On the surface of the wheel fit, near the place of fracture, the hardness ranged from 31 to 44. The harder metal was on the side of the axle first to rupture. On the two cross sections the hardness ranged from 23 to 28. The higher values at the surface of the wheel fit are attributed to mechanical work having been done on that surface in pressing on the wheel, or incidental treatment, rather than to any material difference in the composition of the steel. The microstructure of the steel did not indicate a difference in hardness due to composition at the surface of the axle.



No. 6.—Truck wheels, showing fractured surface of axle just below face of hub.

The metallographic examination, taken at four places on the circumference, 90° apart, showed identical structure throughout.

Tensile tests were made on the metal of the section covered by the wheel fit near the place of fracture. The tests represented the metal, in a longitudinal direction, near the circumference, one-quarter below the surface, and at the center of the axle. Specimens were taken out in duplicate, one set being tested in the natural state of the metal in the forging and one set after the metal was annealed. Three additional specimens were taken from the axle near the middle of its length, in a crosswise direction.

The results of the tensile tests were as follows (specimens 0.50 diameter by 2 inches long):

Location.	Tensile strength, per square inch.	Elongation.	Contraction of area.
Longitudinal specimens, natural state of forging:	*Pounds.*	*Per cent.*	*Per cent.*
Near circumference	75,800	29.0	42.3
One quarter below surface	75,000	29.0	44.3
Center of section	71,200	28.0	40.2
Longitudinal specimens, annealed:			
Near circumference	72,800	31.5	49.2
One quarter below surface	69,500	33.0	51.8
Center of section	68,700	30.0	47.6
Crosswise specimens, natural state of forging:			
Diametrical and on chords	69,300	18.0	18.4
	67,130	15.0	14.8
	70,900	20.0	21.4

The elastic limits of the longitudinal, unannealed specimens were in the vicinity of 45,000 pounds per square inch, which dropped to 37,000 pounds per square inch in the annealed metal. In a crosswise direction the elastic limits were about 30,000 pounds per square inch. The fractures of the longitudinal specimens were fine silky, those of the crosswise specimens lamellar.

The results of the examination of the metal showed a grade of steel had been used which under normal conditions should have enabled the axle to sustain the loads of the tender, which under static conditions were not high. Assuming a load of 20,000 pounds carried by each journal, with center of effort at the middle of the length of the journal, then the bending stress at the inner end would be only 5,186 pounds per square inch. At the inner end of the dust guard section the computed stress would be 4,142 pounds per square inch, while in the vicinity of the actual place of rupture, at the wheel seat, the static stress would be somewhat less than 4,000 pounds per square inch. These are recognized as moderate bending stresses which if not exceeded the axle should carry with safety. The fracture of this and other axles indicates, however, that occasional loads are received greatly in excess of the static loads, the severity of which is accountable for the ultimate failure of axles.

This axle was used with 36-inch wheels. It would, therefore, make about 560 rotations per mile, and the total number of rotations for its mileage of 84,649 miles would be, in round numbers, 47,400,000. Under a constant bending stress as low as 5,186 pounds per square inch the effect of this number of repetitions should not affect the integrity of the axle. In fact the life of the axle under a load of this magnitude should be practically of unlimited duration.

This axle fractured at a place where the bending stresses were not at their maximum, a circumstance which calls for special inquiry. The fracture did not occur at the face of the hub of the wheel, but at a distance within, ranging from three-sixteenths of an inch to seven-sixteenths. From its position it was effectually concealed by the metal of the hub, its presence not admitting of discovery prior to the complete separation of the metal and the failure of the axle. The type of fracture, however, was a common one, and known as a detailed or progressive fracture. A type of fracture which results from a number of repetitions of load. Fractures of this kind are unaccompanied by the development of ductility which is displayed in the usual tests of the metal.

The fracture of this axle started on one side of its cross section, thence extending toward the center. At the time of final rupture only about one-quarter of the cross section remained intact. The final portion was an eccentric section some 3 inches in diameter. The fractured surface presented the usual characteristics witnessed in repeated stress fractures. The earlier fractured portions were hammered smooth by the longitudinal compressive component, which acted on the axle up to the time of final fracture. The portion which failed last had a silky appearance, but was somewhat battered by blows received at the time of the derailment. The fiber stresses in this part of the axle certainly were greatly augmented before final rupture was reached. They must have been increased several fold at the time the axle was reduced to an effective diameter of 3 inches.

Failures of this kind have furnished evidence upon the wide fluctuations of stresses which are received in the track, since there have been instances in which axles, partially ruptured, have been discovered carrying normal loads on diameters of sound metal very much reduced over their primitive dimensions. Such evidence, resting upon a number of examples, leads to the deduction that wide fluctuations of loads are generally encountered in the track and must be provided for in establishing the dimensions of axles. Practically this is a matter not easily fixed.

There are places in which, by reason of the difficulties which surround the determination of the actual working stresses, the problem of providing a proper section, is one of peculiar obscurity. Axles are examples in which it is essential to provide adequate strength to resist loads which in a strict sense are indeterminate. For this reason the failure of an axle of this kind is matter of deep concern, unless some unusual and specific cause for its fracture can be found.

It is believed that an exceptional condition existed in the case of this axle which affected its durability and led to its premature fail-

ure, and which was found in a well-defined circumferential mark scored upon the surface of the wheel fit, and which the plane of rupture followed over a considerable portion of its course. This scored line appeared to have located the incipient place of rupture. In appearance it resembled the effect of the cutting edge of some hard body rather than the mark of an ordinary lathe tool used in the finishing cut on the axle. If not made by a lathe tool, it must have been made by some hard body having substantially the

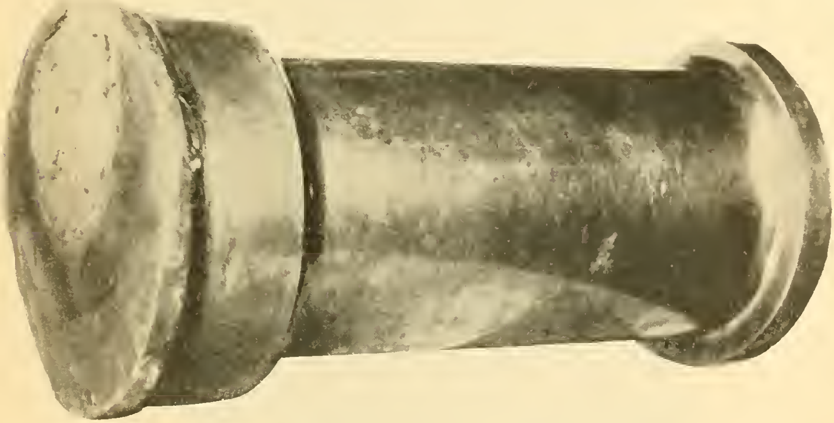
No. 7.—End view of fractured axle, showing character of surface of progressive fracture. Diameter of metal which remained intact up to the time of final fracture, 3 inches.

same diameter as the wheel fit, which feature directs attention to the hub of the wheel as a probable object responsible for the circumferential scoring.

Upon dismantling the axle further evidence was disclosed which directed attention to this part of the wheel fit, namely, the serrations on the cylindrical surface, previously referred to, which were located near the place of rupture. Efforts were directed toward ascertaining why these serrations were present, which apparently attached to the period of machining the rough-turned forging or when pressing on

the wheels. The rough-turned axles were finished at the Baldwin Locomotive Works in lathes which were located in the immediate vicinity of the hydraulic press used for pressing on the wheels. That such marks could have been present on the finished surface of the axle and not attract the attention of the lathe operator is improbable, while their character is unlike what might be expected to occur in the lathe. There appeared no reasonable opportunity for the axle to receive the serrations in transit from the lathe to the press.

Conjecturally the most probable explanation for the cause of their presence, and when made, attaches to the time when the wheels were pressed on the axle. If, by accident, the axle was started askew when it first entered the hub of the wheel, the rapid action of the pump of the hydraulic press might cause damage to the wheel fit before its operation could be arrested. Provided this happened, the presence



No. 8.—Portion of axle detached by plane of fracture at the wheel fit.

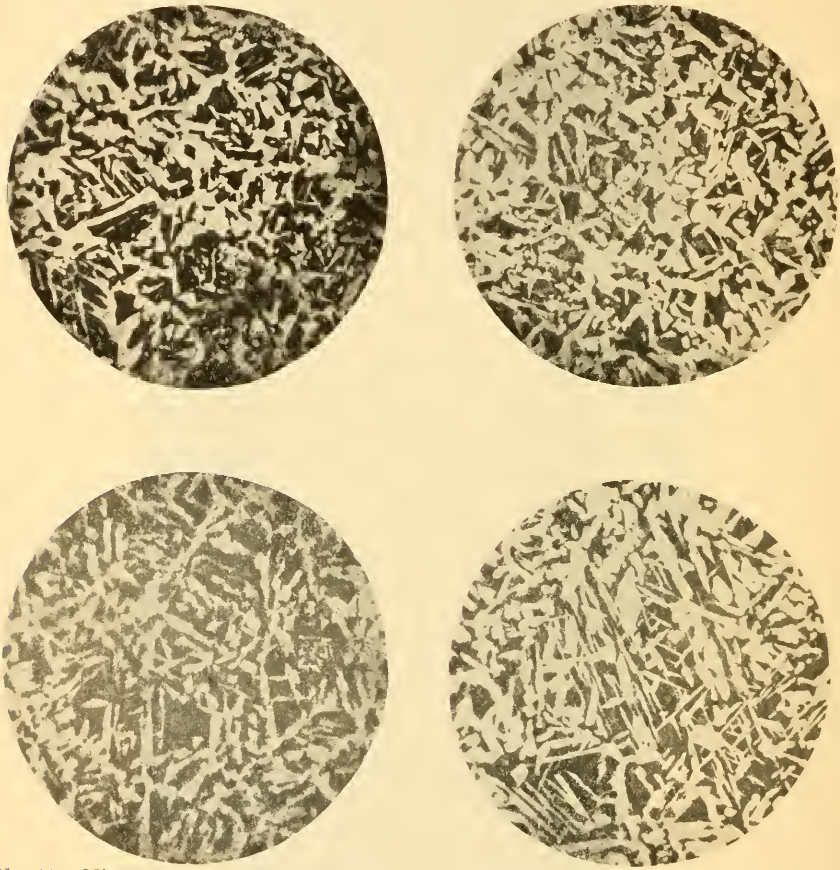
of the sharp circumferential scoring would be consistently accounted for. Furthermore, the removal of the axle or its readjustment normal to the face of the hub would require unusual efforts, and hammering the axle to release it for readjustment is a plausible affair. The choice of tools available to do this is not very great in the vicinity of a wheel press, and such serrations might result from the use of some chance tool found near by.

The records of the Baldwin Locomotive Works do not furnish any information upon this feature of the case. In fact, their records do not show that a Pollak axle was used, but on the other hand they call for a Carnegie axle in its place. Carnegie axles were inspected and accepted by the Baltimore & Ohio Railroad Co. for this tender, but the presence of the brand mark "Pollak" and the initials of the Baldwin Locomotive Works, with the date of pressing on the wheels

No. 9.—Side view of axle at wheel fit, showing serrations on surface adjacent to plane of fracture. Fractured edge on the right of the cut. Microscopic specimens slotted off the left edge of this section.

No. 10.—Side view of axle at wheel fit and dust guard, showing circumferential scoring on wheel fit, which the plane of fracture followed over a part of its course. Fractured edge on the left of the cut.

and the pressures employed, agreeing with the records of the latter company, show that some error was made in the records. Although not important in this instance, cases may arise in which the inspection of the material would involve vital features. On this occasion greater importance attached to the workmanship and the assembling of the wheels upon the axle, which the inspection provided for did not cover.



No. 11.—Microstructure of fractured axle near circumference at wheel fit and near place of fracture. Specimens taken out 90 degrees apart. Magnification, 50 diameters.

The cause of the failure of the axle appears associated with the presence of the circumferential scoring which was on the surface of the wheel fit, and that its endurance in service was impaired by this groove. An illustration bearing upon the behavior of this axle was furnished by duplicate test shafts recently submitted to repeated alternate stresses, similar in kind to the stresses which ruptured this axle. One of the shafts was accidentally scored during the test by

a loose set screw. The place of rupture was located by this scoring, and the number of repetitions of stresses was reduced 664,700 times, apparently by reason of this surface defect. The total number of repetitions of loads sustained by the injured and uninjured shafts were 262,000 and 926,700, respectively. Sharp reentering angles and sudden changes in cross section are recognized as undesirable in material subjected to repeated alternate stresses. Slight surface defects are also detrimental, increasing in gravity with the magnitude of the stresses and with the use of higher or harder grades of steel.

It is problematical how long axles endure in service after rupture actually begins. Annular fractures are at times formed and are probably of slower development than fractures which develop on one side of the axle only.

In conclusion it appears—

That the derailment of train No. 3 was due to the fracture of a tender axle.

That the type of failure was a progressive or detailed fracture, starting from one side of the axle and thence extending inward.

That final rupture occurred when there remained intact only about one-quarter of the original cross section of metal.

That the fracture of the axle occurred on the wheel fit, at a place some three-sixteenths to seven-sixteenths inch within the section covered by the hub of the wheel.

That the location of the place of rupture was probably influenced by circumferential scoring on the surface of the wheel fit, which the plane of rupture followed over a part of its course.

That the scoring was a defect of workmanship incident to the period of finishing the axle or when the wheel was being pressed on the end which subsequently fractured.

The investigation by Mr. Howard showed that steel of good quality was used in the axle which failed, the immediate cause of failure appearing to be the presence of a surface defect on the wheel fit, which place marked the location of rupture. The fracture of an axle of this size is a very disquieting matter, provided no unusual and specific cause is discovered. The influence which surface defects have in limiting the endurance of shafts and axles is well known, and the presence of such a defect on this axle is in a way reassuring, since it removes a doubt which would attach to all axles of this class if no local defect led to its failure.

The customary inspection in this instance did not guard against defects of workmanship, nor in the case of this axle did it afford assurance that the material inspected by representatives of the Baltimore & Ohio Railroad would be used to the exclusion of other material not inspected by them. However, the inspection of the material

in the present case had only an indirect bearing; a more vital feature pertained to the workmanship and assembling of the wheels on the axle.

The axle failed prematurely, the only assignable cause for which is found in the surface defect on the wheel fit, to guard against the recurrence of which is a very obvious desideratum.

The behavior of steel cars is brought into prominence in this accident. In several of its annual reports to Congress the commission has called particular attention to the desirability of all cars used in high-speed passenger-train service being constructed of steel, and in connection with many serious accidents investigated attention has been called to the damage sustained by cars of wooden construction as compared with cars of steel construction.

The accident here under investigation affords another exceptionally interesting opportunity for a study of the behavior of the all-steel passenger car in a serious derailment. The train involved was running on straight track at the rate of 57 miles per hour. Although the impact of the heavy all-steel sleeping car Rachita against the end of the modern steel-truss bridge, while moving at high speed, damaged the bridge to such an extent that it collapsed, throwing the sleeping car to the track below, a distance of 20 or 25 feet, yet the car was not seriously damaged, and none of its occupants killed or seriously injured. While, of course, it is conjectural what would have happened had this car been of wooden construction, yet it is probable that had a wooden car been involved it would have been seriously damaged, if not destroyed, with the majority of its occupants killed or seriously injured.

In this connection attention is also called to the report covering the investigation of the accident which occurred on the Alabama Great Southern Railway near Livingston, Ala., on September 18, 1914. The accident involved a passenger train, derailed while moving at a speed estimated to have been 50 miles per hour. In that accident two steel underframe coaches were very badly damaged, many of the occupants being killed, while the wooden car immediately ahead of these two cars was destroyed. In the report covering that accident it was stated that:

> While none of the steel-underframe cars was entirely destroyed, as was the wooden coach, nevertheless it appears questionable, when comparing the damage sustained by the different types of cars in this train, whether the steel underframe type of car afforded a materially greater degree of safety to passengers than the wooden coach. Steel underframes will probably prevent the buckling or breaking in two of a car, and in that respect cars so constructed are undoubtedly an improvement as compared with cars built entirely of wood; if practically everything above the steel underframe is to be destroyed in an accident, however, it is apparent that but little increased protection to passen-

gers is afforded. The fifth car in the train, an all-steel Pullman sleeping car, was practically uninjured, all the damage sustained by it being confined to the trucks and running gear.

The facts developed in that investigation, as well as in the one here under discussion, strengthen previous recommendations, made in accident investigation reports, as well as in the annual reports of the commission to Congress, that the greatest protection to passengers in high-speed trains can be afforded only by the use of all-steel cars.

Respectfully submitted.

H. W. Belnap,
Chief Division of Safety.

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